

CASE FILE COPY

N 69 38363

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-52680

NASA TM X-52680

ROUND TRIP TRAJECTORIES WITH STOPOVERS AT BOTH MARS AND VENUS

by E. A. Willis, Jr. and J. A. Padrutt
Lewis Research Center
Cleveland, Ohio
1969

ROUND TRIP TRAJECTORIES WITH STOPOVERS
AT BOTH MARS AND VENUS

By

E. A. Willis, Jr. and J. A. Padruitt

ABSTRACT

Round trip interplanetary trajectories are studied that stop over at both Mars and Venus before returning to Earth. Such trips fall roughly midway between conventional opposition - and conjunction - class Mars missions, in terms of propulsive effort, trip time and staytime.

ROUND TRIP TRAJECTORIES WITH STOPOVERS AT BOTH MARS AND VENUS

By

E. A. Willis, Jr. and J. A. Padruitt

SUMMARY

This report considers a class of efficient interplanetary round trip trajectories that involve entering parking orbits at both Mars and Venus before returning to Earth. Using the conventional two-body, impulsive trajectory model, it is found that:

(a) Propulsive effort requirements and trip times for these combined Mars-Venus stopover trajectories need not be greatly higher than for a mission to Mars or Venus alone; in any case these quantities are less than the totals for separate trips to Mars and Venus.

(b) Trajectories recur on a 6.4 year major cycle, and there are seven low-energy launch opportunities within that period.

(c) Three of these opportunities are particularly desirable, in that they involve optimum trip times of only around 700 days; this may be reduced to 600 days without a major penalty in propulsive effort ΔV . Two others require optimum trip times of 840-890 days, but these may be reduced to about 750 days before a large penalty is incurred. The remaining two cannot be reduced much below 1000 days trip time.

(d) Optimum stay times at Mars tend to be short (e.g., 10 days) for short trip times, but can be increased to 50 days for a very minor ΔV increase. Optimum Venus stay times are generally in the 25 - 75 day range.

INTRODUCTION

Manned missions to Mars and Venus may eventually become the prime focus of the national manned spaceflight program. Such missions clearly involve a new order of difficulty when compared to present orbital and lunar operations, and will depend upon the

proper functioning of systems which have yet to be developed. In order to define the requirements for these systems, it is now appropriate to evaluate preferred mission modes and trajectories.

Numerous studies have been made of manned missions to Mars or to Venus that involve entering a capture orbit at the destination planet. (See for instance, refs. 1-10.) Several of these single-planet stopover trajectories seem attractive on their own merits; nevertheless, it is not clear that two of them taken together comprise an optimum program for investigating both Mars and Venus. Therefore, the present report presents and analyzes a novel alternative class of trajectories, illustrated in figure 1, in which the space vehicle stops over at both Venus and Mars before returning to Earth.

In brief, the trajectory begins in a low Earth parking orbit, proceeds to elliptic parking orbits at Mars and then Venus (or vice versa), and finally terminates with atmospheric braking at Earth return. The computational methods and basic assumptions of reference 6 were used together with planetary data from reference 10. Numerical results (based on minimum ΔV) are presented for launch opportunities from 1980 to 1996, trip times from 550 to 1100 days, and stay times at each planet ranging from 10 to several hundred days. These are compared with the Venus-swingby, Mars stopover mission in four typical launch years.

RESULTS AND DISCUSSION

Trajectory Characteristics

Minimum-energy trajectories. - Table I presents seven typical minimum-energy trajectories. These consist of Hohmann-type (optimum travel time and travel angle) interplanetary transfers, with optimum stay time at each planet.

TABLE I. - MINIMUM ENERGY TRAJECTORIES

(a) Earth-Mars-Venus-Earth

Opposition Year	$\Sigma\Delta V$ (km/sec)	Total Trip Time (days)	Stay Time @ Mars (days)	Stay Time @ Venus (days)
1980	9.382	893.7	78.2	177.3
1982	9.252	1294.2	273.5	340.0
1984	9.339	1088.8	200.1	250.2

(b) Earth-Venus-Mars-Earth

Opposition Year	$\Sigma\Delta V$ (km/sec)	Total Trip Time (days)	Stay Time @ Mars (days)	Stay Time @ Venus (days)
1980	8.738	859.3	10.02	179.6
1982	8.700	1027.0	133.2	264.9
1984	8.896	1229.7	600.5	10
1986	9.321	1443.5	78.1	767.8

It is often possible to reduce the long trip times shown by deducting an appropriate synodic period from one of the stay times. A second local minimum was found in this manner, at a lower trip time and for little $\Sigma\Delta V$ penalty, for three out of the seven typical opportunities shown in the table. The results are presented in figure 2 where trip time is plotted in part (a) and $\Sigma\Delta V$ in part (b), as functions of launch year from 1980 to 1996 A.D. Note that results are periodic with a major cycle or repeating period of about 6.4 years. This contains almost exactly three Earth-Mars synodic periods and four Earth-Venus synodic periods and hence, seven typical launch opportunities.

It is evidently possible to obtain low energy trips with trip times of 650 to 700 days in 1982, 1984, 1986, and the 6.4 year repeats of these trips. In 1980 (and its repeats) both profiles require about 850 days, and it appears to be more difficult to obtain short trip times in that period; however, the ΔV is still quite low. The remaining two trips in one repeating period do not seem capable of being reduced below about 1000 days trip time for a reasonable $\Sigma\Delta V$.

The stay times associated with the preceding trajectories are quite variable. The short-trip-time trajectories, however, tend to have short stay times at Mars, and this (depending upon mission objectives) could be an undesirable feature.

Effect of trip time. - The effects of trip time T_t on $\Sigma\Delta V$ in the difficult 1980 period are considered in figure 3(a). The heavy solid curve represents the present two-planet stopover trajectories; the other curve should be neglected for the time being.

Note there is a mild "knee" at about 720 days; $\Sigma\Delta V$ increases quickly for shorter times. Stay times (not illustrated) only

varied slowly at long trip times, but began to decrease abruptly (to the assumed minimum of 10 days) at this same trip time. It was found also that stay times could be constrained to be at least 50 days without major $\Sigma\Delta V$ penalty.

The solid curves in figures 3(b) - (d) show the effect of T_t on $\Sigma\Delta V$ for the three most attractive launch years. (The dash dot curves will be discussed later). Clearly, the trip times may be reduced to 600 days or perhaps a bit less in these three periods, without incurring major $\Sigma\Delta V$ penalties.

Comparison of Trajectory Modes

In this section, the previously-discussed characteristics of Mars-Venus stopover trajectories are compared with the reference 10 results for Venus-swingby trajectories¹ to Mars.

Propulsive effort and trip times. - Figure 3(a) portrays the $\Sigma\Delta V$ - T_t behavior of the two trajectory modes, again for the 1980 opportunity. The present results are indicated by the heavy solid curve and were previously described. Note that $\Sigma\Delta V$'s comparable to those of conventional opposition-class mission around 15 km/sec can be obtained for trip times of 600 days or more. For Venus swingby trajectories (the dash, dot curve), the minimum $\Sigma\Delta V$ occurs at 700 days trip time, and at this value of T_t the two-planet mode involves about a 4 km/sec ΔV penalty. If, however, the trip time is extended to 770 days, the penalty is under 1 km/sec. At trip times greater than about 850 days, the conjunction class trips (not illustrated) yield the lowest $\Sigma\Delta V$.

Thus, in 1980, the present trajectory does not require a greatly increased $\Sigma\Delta V$ (compared to the swingby mode) but it does require a rather long trip time. The more attractive opportunities of 1982-6 are illustrated in figures 3(b) - (d). As before, the Mars-Venus stopovers are shown by the heavy solid curves, while Venus-swingbys are indicated by the dash dot curve. In 1982 - 1986, the two profiles are more competitive in the minimum- ΔV neighborhoods around 600 days, with the swingby being progressively better at shorter trip times and the Mars-Venus stopover being highly competitive or somewhat superior at longer times. As in 1980, the conjunction trip (not illustrated) would yield the lowest $\Sigma\Delta V$ for trip times greater than 850 or 900 days. Thus, in 1982-1986 the present trajectory mode is competitive for trip times ranging from about 600 to 875 days.

¹All trajectories discussed herein use elliptic parking orbits at Venus and Mars ($e = 0.9$) and atmospheric braking at Earth return with reentry speed $\leq 52\ 000$ fps.

Mission objectives capability. - If $\Sigma\Delta V$ and trip time were the only considerations, there would be little need for the present class of trajectories; i.e., existing Mars or Venus trajectory modes generally yield shorter trip times for comparable $\Sigma\Delta V$'s or lower total $\Sigma\Delta V$'s at comparable trip times.

On the other hand, Venus is also a legitimate object for scientific and technical curiosity, and there are several major objectives that would either require or benefit significantly from the presence of a properly trained crew in orbit. Thus, the present trajectories could appropriately be compared with the sum of individual Mars and Venus round trips. The total combined $\Sigma\Delta V$'s and T_t 's exceed 17 km/sec and 1000 days, respectively. On this basis the Mars-Venus stopover is clearly superior to any combination of Mars-only and Venus-only round trips.

CONCLUDING REMARKS

In this report, a class of round trip trajectories with stopovers at both Mars and Venus has been studied. The results lead to the following conclusion:

(a) $\Sigma\Delta V$ requirements are not greatly higher than those of the best existing trajectory modes which go to Mars or Venus only, and are distinctly lower than the sum of these two.

(b) There are seven low-energy launch opportunities within each 6.4 year repeating period. Of these, three involve only moderate (under two years) trip times, two require very long (over three years) times, and two require an intermediate value of about two and a half years. Four of the seven visit Venus first and Mars second, while the order is reversed for the remaining three.

(c) By selecting the best double stopover profile (e.g., Mars-first) in each period, a minimum energy family can be constructed which requires trip times of only 650-700 days in three out of the seven opportunities and about 850 in the fourth. These values can be decreased to about 600 days and 720 days, respectively, without major $\Sigma\Delta V$ penalty.

(d) Stay times tend to be short (e.g., 10 days) especially at Mars, but can be lengthened to about 50 days without major $\Sigma\Delta V$ penalty.

From the foregoing, it may be inferred that, if Venus as well as Mars is a major manned spaceflight goal, then the present class of trajectories is of legitimate interest and should be taken into account in future mission studies. In particular, vehicle

weight studies for the two-planet trajectories should be performed; results would then be optimized on a weight basis rather than $\Sigma\Delta V$; and a rationale must be established for comparing the present trajectories with those which stopover at only one planet.

Lewis Research Center

National Aeronautics and Space Administration

Cleveland, Ohio, September 4, 1969

126-15-13

REFERENCES

1. Thibodeau, Joseph R., III: Use of Planetary Oblateness for Parking-Orbit Alinement. NASA TN D-4657, 1968.
2. Himmel, S. C.; Dugan, J. F., Jr.; Luidens, R. W.; and Weber, R. J.: A Study of Manned Nuclear-Rocket Missions to Mars. Aerospace Eng., vol. 20, no. 7, July 1961, pp. 18-19, 51-58.
3. Knip, Gerald, Jr.; and Zola, Charles L.: Three-Dimensional Trajectory Analysis for Round-Trip Missions to Mars. NASA TN D-1316, 1962.
4. Zola, Charles L.; and Knip, Gerald, Jr.: Three-Dimensional Trajectory Analysis for Round-Trip Missions to Venus. NASA TN D-1319, 1962.
5. Willis, Edward A., Jr.: New Class of Optimal Interplanetary Trajectories with Specified Trip Time. Paper 65-66, AIAA, Jan. 1965.
6. Willis, Edward A., Jr.: Optimization of Double-Conic Interplanetary Trajectories. NASA TN D-3184, 1966.
7. Doll, John R.: Earth-Orbit Masses for Five-Impulse Mars Stopover Missions in 1980. J. Spacecraft Rockets, vol. 5, no. 5, May 1968, pp. 517-521.
8. Sohn, Robert L.: Venus Swingby Mode for Manned Mars Missions. J. Spacecraft Rockets, vol. 1, no. 5, Sept.-Oct. 1964, pp. 565-567.
9. Deerwester, Jerry M.: Initial Man Savings Associated with the Venus Swingby Mode of Mars Round Trips. Paper 65-89, AIAA, Jan. 1965.
10. Anon.: Planetary Flight Handbook. Vol. 3 of Space Flight Handbooks. NASA SP-35, Pt. 6, 1968.

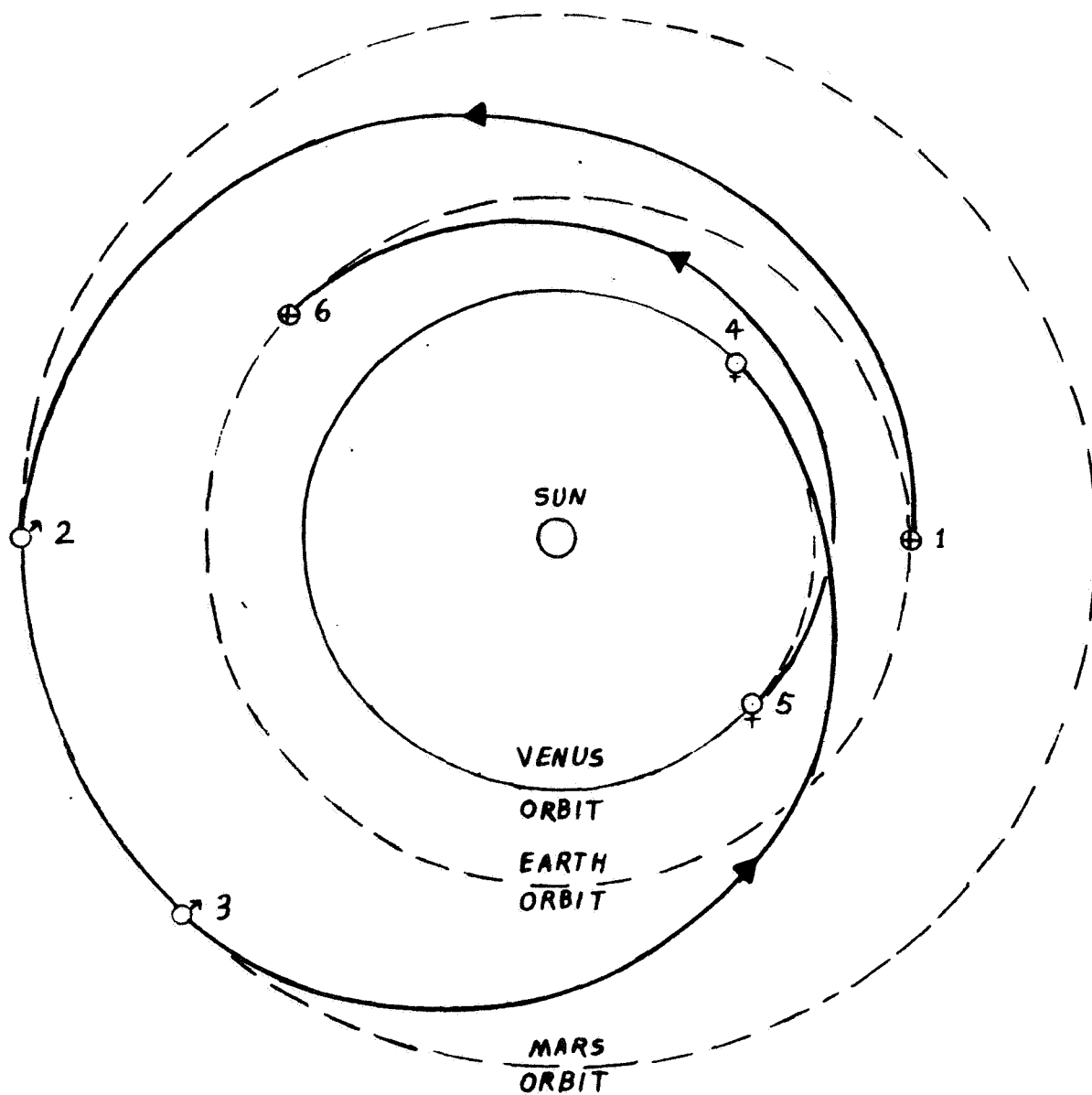


FIGURE 1.- TYPICAL TWO-PLANET STOPOVER
TRAJECTORY. (EARTH - MARS - VENUS
- EARTH, 1980)

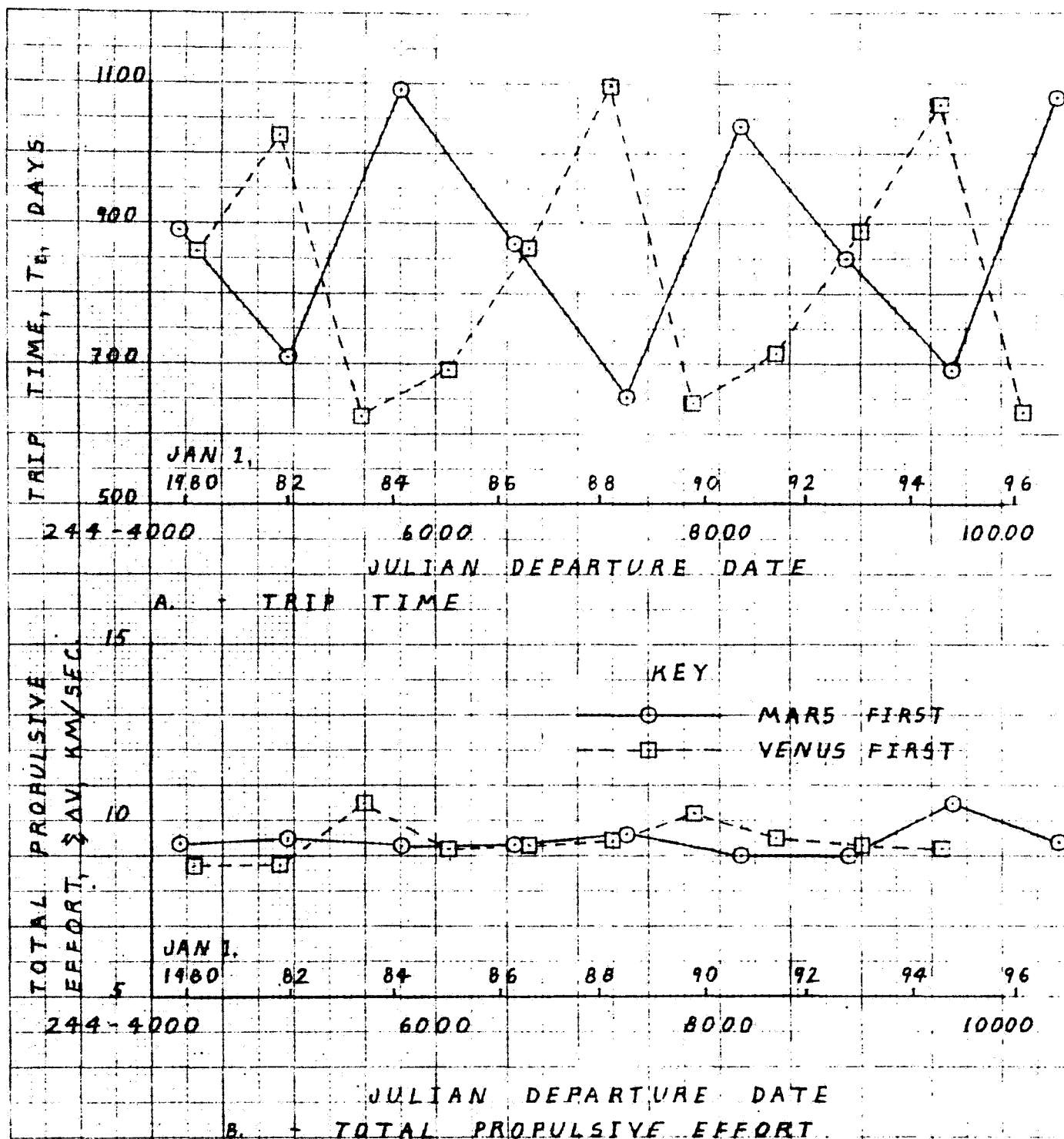


FIGURE 2 - CHARACTERISTICS OF TWO - PLANET
STOPOVER TRAJECTORIES (OPTIMUM
TRIP TIME AND STAY TIME).

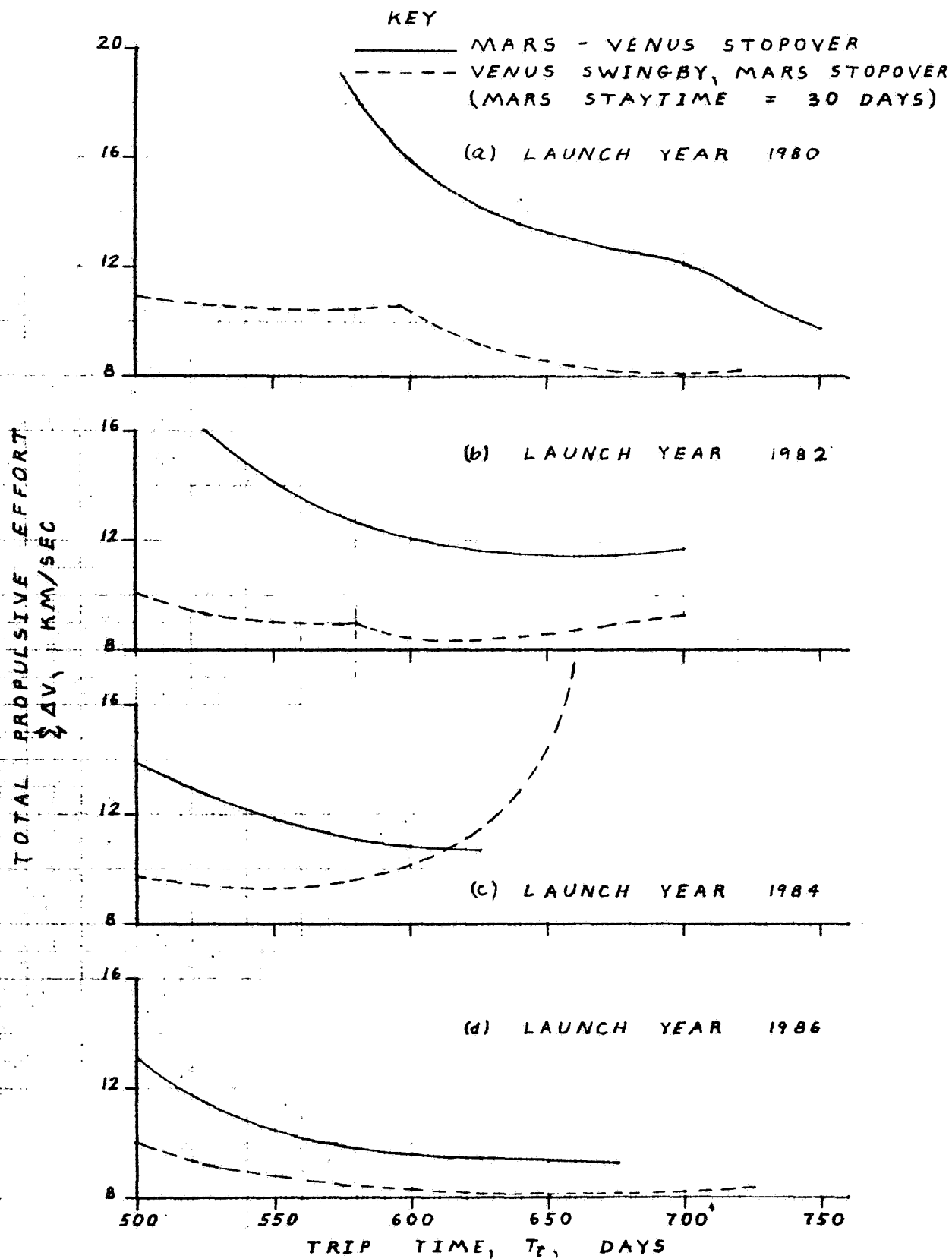


FIGURE 3 - EFFECT OF TRIP TIME ON TWO - PLANET STOP-OVER AND VENUS - SWINGBY TRAJECTORIES TO MARS. LAUNCH YEARS, 1980, 1982, 1984, 1986.